Triakis Corporation

Simulator Requirements Specification

For the

Shuttle Remote Manipulator System

A NASA CI03
SARP Initiative 583
IVV-70 Project

Table of Contents

Table of Figures

1. Introduction

This specification is being developed in support of a research project funded by the NASA OSMA Software Assurance Research Program (SARP) during the fiscal year 2003 Center Initiatives (CI03) effort. Triakis will create a simulation of the Shuttle Remote Manipulator System (SRMS) to be used as a vehicle for exploring the concepts described in section 2 of Triakis proposal number TC_G020614. This document presents the simulator-specific requirements that will be used for developing the virtual system simulation of the system described in the SRMS System Requirements Specification (SARP-I583-001).

1.1 Simulator purpose

The simulator specified herein will provide the environment in which the virtual SRMS will function. This simulator is being developed for use in a research project aimed at investigating the benefits of using executable specifications (ES') and detailed executables (DEs) in a virtual environment simulation for increasing software assurance.

More specifically, this simulator will be used to evaluate the extent to which the Triakis concept of ES' achieves unambiguous communication of system requirements thereby reducing errors induced by interpretation of ambiguous specifications. It will also be used to evaluate the potential that substituting a DE hardware simulation running actual embedded software, in place of the ES, has for reducing costs and maintaining test consistency through reuse of unmodified system level tests.

Further, new methods of gathering software metrics through use of the simulator will be sought, explored, and evaluated. The use of a virtual system simulator developed for this project will be used to evaluate other potential benefits that its virtual system integration laboratory (VSIL) environment offers in support of general testability, independent validation & verification (IV&V), reliability, and safety.

1.2 Simulator scope

This document specifies the characteristics of the SRMS simulator only. Triakis is creating this virtual system for its own use as a vehicle to facilitate the research goals stated in Triakis proposal number TC_G020614. The simulator created through this effort will be developed only to the extent required to support exploration of the concepts on which our research is focused.

1.3 Definitions, acronyms, and abbreviations

CCTV	Closed-Circuit Television
CI03	Center Initiative for fiscal year 2003
DE	Detailed Executable
ES	Executable Specification
EVA	Extra Vehicular Activity
IV&V	Independent Verification and Validation
N/A	Not Applicable
NASA	National Aeronautics & Space Administration
OSMA	Office of Safety and Mission Assurance
PDRS	Payload Deployment and Retrieval System
RHC	Rotational Hand Controller
RMA	Remote Manipulator Arm
RMS	Remote Manipulator System
RMSCC	RMS Control Computer
SARP	Software Assurance Research Program

SRMS Shuttle Remote Manipulator System
THC Translational Hand Controller
VSIL Virtual System Integration Laboratory

1.4 References

http://spaceflight.nasa.gov/shuttle/reference/index.html NASA Shuttle Reference web site
http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/sts-deploy NASA PDRS web page
ISBN 0-345-34181-3 The Space Shuttle Operator's Manual (Revised Edition) by Joels, Kennedy & Larkin Ballantine books, 1988
SARP-I583-001 System Requirements Specification for the Shuttle Remote Manipulator System
TC_G020614 Triakis proposal to NASA for the SARP (Solicitation No: NRA SARP 0201) 14 June 2002

1.5 SRMS Overview

While this specification addresses requirements for the simulator itself, those requirements are, to a great extent driven by the system requirements. Consequently, the following excerpt from the NASA PDRS web page has been included here to provide an overview of the real-world SRMS:

The payload deployment and retrieval system (PDRS) includes the electromechanical arm that maneuvers a payload from the payload bay of the space shuttle orbiter to its deployment position and then releases it. It can also grapple a free-flying payload, maneuver it to the payload bay of the orbiter and berth it in the orbiter. This arm is referred to as the remote manipulator system (RMS).

The shuttle RMS is installed in the payload bay of the orbiter for those missions requiring it. Some payloads carried aboard the orbiter for deployment do not require the RMS.

The RMS is capable of deploying or retrieving payloads weighing up to 65,000 pounds. The RMS can also be used to retrieve, repair and deploy satellites; to provide a mobile extension ladder for extravehicular activity crew members for work stations or foot restraints; and to be used as an inspection aid to allow the flight crew members to view the orbiter's or payload's surfaces through a television camera on the RMS.

2. General SRMS description

This excerpt from the NASA PDRS web page is given here to provide a general SRMS description for informational and reference purposes as may be required by the simulator designer.

The basic RMS configuration consists of a manipulator arm; an RMS display and control panel, including rotational and translational hand controllers at the orbiter aft flight deck flight crew station; and a manipulator controller interface unit that interfaces with the orbiter computer. Normally, only one RMS is installed during a shuttle mission, on the left longeron of the orbiter payload bay.

The RMS arm is 50 feet 3 inches long, 15 inches in diameter, and has six degrees of freedom. The six joints of the RMS correspond roughly to the joints of the human arm with shoulder yaw and pitch joints; an elbow pitch joint; and wrist pitch, yaw and roll joints. The end effector is the unit at the end of the wrist that actually grabs, or grapples, the payload.

The RMS can only be operated in a zero gravity environment, since the arm dc motors are unable to move the arm's weight under the influence of Earth's gravity. Each of the six joints has an extensive range of motion, allowing the arm to reach across the payload bay, over the crew compartment or to areas on the undersurface of the orbiter. Arm joint travel limits are annunciated to the flight crew arm operator before the actual mechanical hard stop for a joint is reached.

One flight-crew member operates the RMS from the aft flight deck control station, and a second flight-crew member usually assists with television camera operations. This allows the RMS operator to view RMS *operations through the aft flight deck payload and overhead windows and through the closed-circuit television monitors at the aft flight deck station.*

The orbiter's CCTV aids the flight crew in monitoring PDRS operations. The arm has provisions on the wrist joint for a CCTV camera that can be zoomed, a viewing light on the wrist joint and a CCTV with pan and tilt capability on the elbow of the arm. In addition, four CCTV cameras in the payload bay can be panned, tilted and zoomed. Keel cameras may be provided, depending on the mission payload. The two CCTV monitors at the aft flight deck station can each display any two of the CCTV camera views simultaneously with split screen capability. This shows two views on the same monitor, which allows crew members to work with four different views at once. Crewmembers can also view payload operations through the aft flight station overhead and aft (payload) viewing windows.

The arm has a number of operating modes. Some of these modes are computer-assisted, moving the joints simultaneously as required to put the end point (the point of resolution, such as the tip of the end effector) in the desired location. Other modes move one joint at a time; e.g., single mode uses software assistance and direct and backup hard-wired command paths that bypass the computers.

Four RMS manually augmented modes are used to grapple a payload and maneuver it into or out of the orbiter payload retention fittings. The four manually augmented modes require the RMS operator to use the RMS translational hand controller (THC) and rotational hand controller (RHC) with the computer to augment operations.

The THC and RHC located at the aft flight deck station are used exclusively for RMS operations. The THC is located between the two aft viewing windows. The RHC is located on the left side of the aft flight station below the CCTV monitors. The THC and RHC have only one output channel per axis. Both RMS hand controllers are proportional, which means that the command supplied is linearly proportional to the deflection of the controller.

There are two types of automatic modes that can be used to position the RMS arm: operator-commanded and preprogrammed.

The operator-commanded automatic mode moves the end effector from its present position and orientation to a new one defined by the operator via the keyboard and RMS CRT display. The arm moves in a straight line to the desired position and orientation and then enters the hold mode.

The preprogrammed auto sequences operate in a manner similar to the operator-commanded sequences. Instead of the RMS operator entering the data on the computer via the keyboard and CRT display, the RMS arm is maneuvered according to a command set programmed before the flight, called sequences. Each sequence is an ordered set of points to which the arm will move. Up to 200 points may be preprogrammed into as many as 20 sequences.

The standard end effector can be considered the hand of the RMS. It is a hollow can-like device attached to the wrist roll joint at the end of the arm. Payloads to be captured by the standard end effector must be equipped with a grapple fixture. To capture a payload, the flight crew operator aligns the end effector over the grapple fixture probe to capture it. The end effector snare consists of three cables that have one end attached to a fixed ring and one attached to a rotating ring.

The description provided is intended to give a general picture of system functionality upon which our virtual system will be modeled. The features actually implemented and the fidelity of this virtual SRMS representation will be dependent upon what is needed to support our overall research goals.

Most of the parts comprising the simulated SRMS will be implemented as abstract, high-level ES parts, while other ES parts will be simulated with great fidelity. The SRMS control computer part will be implemented with the highest level of detail since it will be used to explore the implications of using the same test cases developed for the ES-based simulator, on the simulator running the DE in its place.

Unless otherwise indicated, subsequent references to all elements of the SRMS and surrounding systems within this document are to be construed as referring to the virtual system elements within the simulator being developed and not the actual SRMS (in use on the NASA shuttle program) on which the derived system is based.

3. Simulator performance characteristics

R1: The SRMS simulation shall be created using the Triakis IcoSim simulator application running in a Microsoft Windows® operating system environment.

R2: The SRMS simulation shall provide for user operation via standard computer and mouse devices.

R3: The virtual SRMS shall implement all of the requirements identified in the SyRS for the SRMS (Triakis document SARP-I583-001).

3.1 System context

The SRMS described in the SyRS is intended be a self-contained system with few connections to the virtual shuttle within which it will function. Figure 1 depicts the actual RMA (upon which this simulation is based) with major parts identified and its typical location within the shuttle orbiter. Neither the manipulator positioning mechanism nor a functioning end effector will be implemented in this SRMS.

R4: The SRMS shall be rendered within a 3-D graphical representation of the shuttle orbiter cargo bay, and attached to the portside cargo door support longeron as indicated in Figure 1.

R5: Placement of the SRMS within the virtual shuttle orbiter shall be such that simulation of the SRMS provides easy visual recognition that it represents its real-world counterpart.

R6: The SRMS shall draw power from the space shuttle 28VDC and 115VAC/400Hz power supplies as required to function as specified.

R7: The RMS control & display panel and the closed circuit television (CCTV) monitors that the crew employs in the operation of the SRMS shall be located on the orbiter flight deck at the aft crew station.

3.2 Major simulated components

R8: The SRMS simulator shall comprise three principal simulated elements:

a) A remote manipulator arm (RMA) (Figure 1),
b) A RMS control & display panel (Figure 2), and
c) A RMS control computer (RMSCC).

R9: Simulated CCTV monitors shall also be implemented as a means of visually monitoring RMA activity during operation.

R10: The RMSCC shall provide the main interface between the RMS control & display panel and the RMA itself.

R11: All elements within the virtual system shall be implemented as ES' with an amount of detail commensurate with the element's importance to our research interests.

R12: The RMSCC shall initially be implemented as a high-fidelity ES.

R13: The RMSCC ES shall be validated and verified through the iterative development and application of a suite of tests designed to exercise and verify conformance to the functional system requirements specified in the SyRS for the SRMS (Triakis document SARP-I583-001).

R14: The RMSCC shall subsequently be implemented as a DE.

a) The DE part boundary (interfaces to external elements) shall be identical to that of the RMSCC ES part.
b) Embedded software shall be developed to implement the RMSCC functionality specified herein, and to run on the DE simulated host processor.
c) The DE part shall be directly exchangeable with its ES counterpart such that there shall be no functional differences between running the SRMS simulation with the ES or with the DE.
d) The SRMS simulation using the DE shall pass all of the tests that the SRMS simulation using the ES passes.

Figure 2 is an illustration of the RMS control & display panel that exists in the real-world shuttle at the aft crew station. Selection of the various operational modes and states is achieved through operator command via the RMS control & display panel. The virtual SRMS will not implement all of the functions and modes incorporated in its real-world counterpart and therefore will not make use of some of the buttons, indicators, switches, and switch states shown on the panel in Figure 2.

Note: Manually augmented control of the real-world SRMS is accomplished through the controls provided on the RMS control & display panel. Because neither a mouse nor a keyboard can adequately mimic the 3-axis THC used by the real-world counterpart, the simulator may be designed to implement manual modes through control of one or two dimension movements.

3.3 System modes and states

The SRMS simulator shall implement the system modes and states specified in the SyRS (SARP-I583-001)

3.4 Major system capabilities

The SRMS is intended to provide the virtual capabilities of its real-world counterpart to the extent necessary to facilitate achieving the research goals that this system supports.

3.5 Testability

R15: In order to exercise the system response to failures, a minimum of 5 of the simulated systems parts shall be created with internal failure modes that can be invoked under test control.

R16: A full set of tests designed to verify SRMS conformance to the functional characteristics specified in the SyRS shall be written to exercise the virtual SRMS.

3.6 System constraints & safety considerations

As far as the virtual SRMS is concerned, most constraints of this system are imposed for safety related reasons. Given its movement capability, the RMA has the potential to collide with the shuttle orbiter as well as payload modules within the orbiter's cargo bay. Careful consideration must be given in all aspects of the virtual SRMS design to prevent such collisions, though virtual in nature, from occurring. However, since no real hardware will be built, there is no requirement to implement safety constraints considerations.

4. System interfaces

Since the SRMS is essentially a self-contained, virtual system running on a Windows-based PC, there are no interfaces to external systems that require specification. Interfaces through which the operator interacts with the SRMS are found on the RMS control & display panel (Figure 2), and are largely specified in section 2.2 and section 2.3 of this document. All remaining user interface features of the RMS control & display panel to be used in the virtual SRMS are specified in the requirements that follow.

5. Simulator testing

No formal test documentation on the simulator will be generated for this project. All parts of the simulator will be tested to the extent that they need to function to serve the purposes of our research. Selected parts have been extensively tested through use on commercial projects (e.g MPC-555, DC Motors, etc.) and the parts generated in support of this effort will be verified to the extent that the project requires.

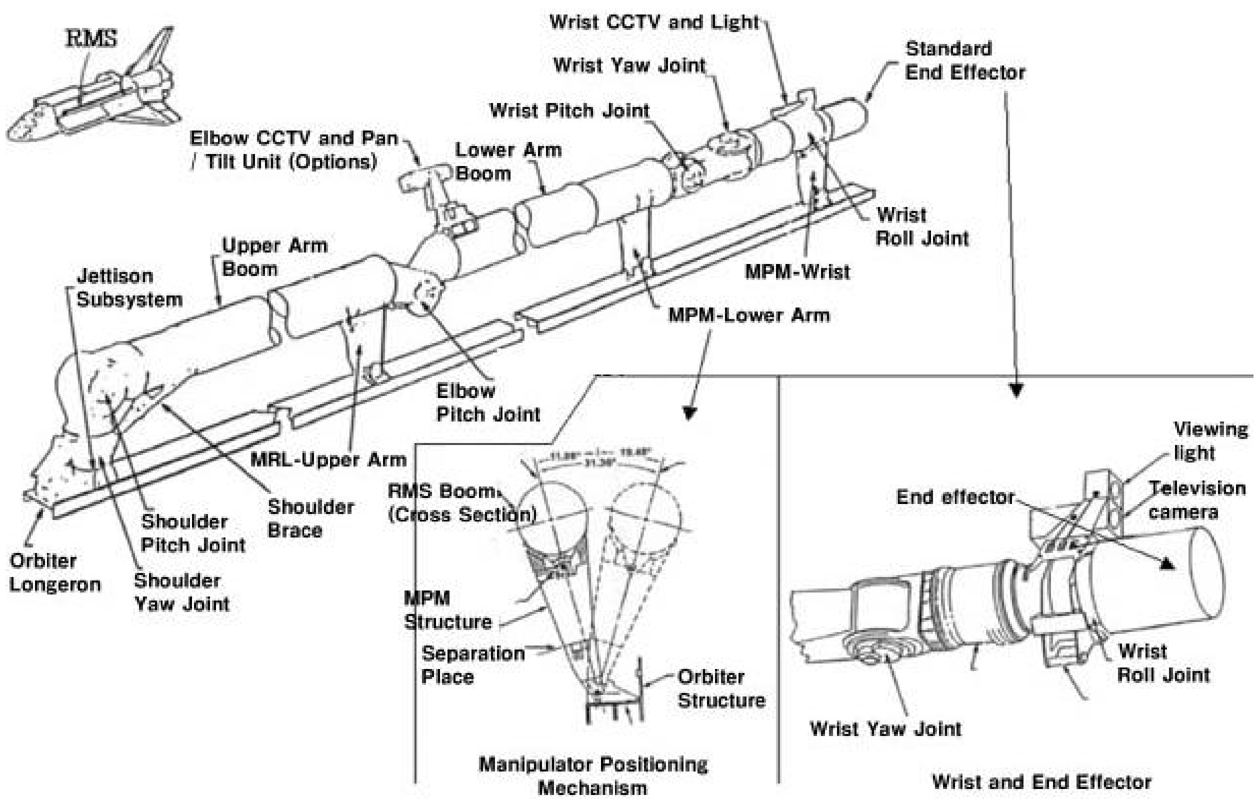

Figure 1: Remote Manipulator Arm

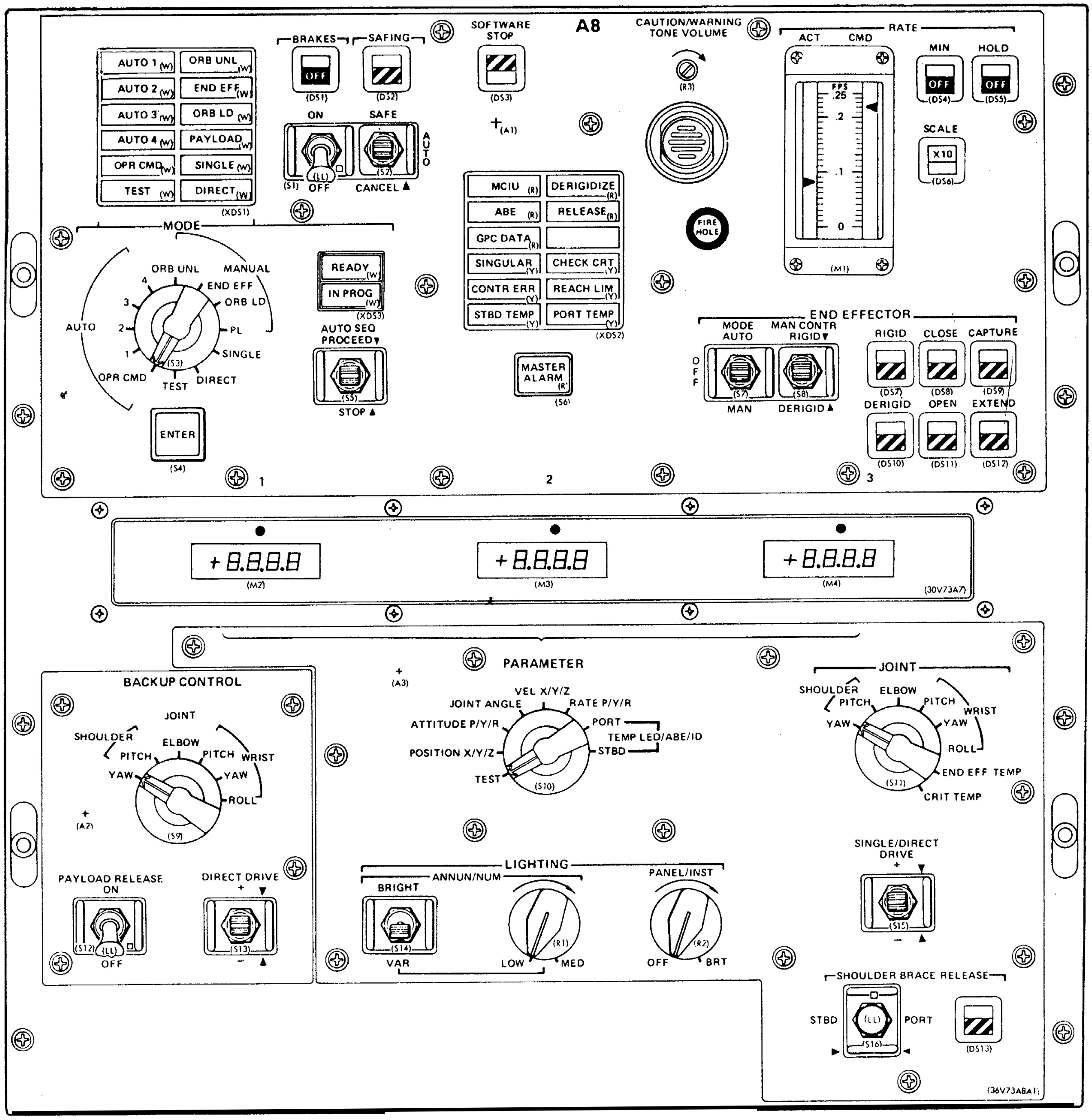

Figure 2: RMS Control & Display Panel (CCTV monitors not shown)